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THE DIMENSIONS OF OUR STELLAR SYSTEM

By WILLIAM H. PICKERING

Our system is believed to consist of a spheroidal cluster of stars and gas, surrounded by the stellar clouds of the galaxy, extending far beyond the cluster itself. Not only are the boundaries of the galactic stars hopelessly remote as far as our present methods of measurement are concerned, but they fade out very irregularly, both in galactic longitude and latitude. At the galactic poles on the other hand the stars are fairly uniformly distributed, and their distances are not so great but that we find them almost if not quite within our reach.

A count has therefore been made of all the stars included in the *Henry Draper Catalogue*, lying between $\alpha\, 0^h 00^m$ and $1^h 20^m$ and $\delta -18°$ and $-38°$ about the south galactic pole, and between $\alpha\, 12^h 00^m$ and $13^h 20^m$ and $\delta +18°$ and $+38°$ about the north. A further count of the galactic region lying between $\alpha\, 0^h 00^m$ and $2^h 23^m$ and between $\delta +50°$ and $+70°$ has been made. This region is of the same area as the other two, a little short of 400 square degrees, and we will deal with it first. In Table I the number of stars is entered according to their types and magnitudes. The data are so arranged that all the stars lying for instance between magnitudes 5.0 and 5.9, inclusive, are counted as of magnitude 5.5, and all those lying between types A0 and A9 are counted as of type A5. Besides those recorded in the table there were 13 variable stars whose limiting magnitudes are not given, of which 9 belonged to type M, and the others to types B, F, and K. For this region the catalog also contains 3 stars of type O, 2 of type R, and a nebula of type P. There are no stars of type N.

If the stars were of uniform average brightness, and uniformly distributed in space, the number brighter than a given magnitude could be represented by the well known formula $y = ax^n$, where a is a constant, x equals the constant 3.981, and n is the number of magnitudes. As is also well known, in the actual distribution, taking the stars as a whole, not only is the number 3.981 never reached, but as we recede farther and farther from the Sun the value of x becomes constantly smaller and smaller. Both of these facts indicate that in the remoter regions of the heavens the stars are farther apart, and possibly also of less absolute magnitude. An examination of the table leads us to believe that up to the ninth magnitude it is fairly complete. Starting with magnitude 4.5 we will substitute n-4.5 for n in the above formula and obtain the equation $\log y = (n-4.5) \log x + \log a$. By plotting the magnitudes $(n-4.5)$ as abscissas, and the logarithm of the number of stars brighter than a given magnitude as ordinates, we obtain graphs which approximate to straight lines, and give us the values shown in Table II. Using these values, in Table III under each type are shown the observed and computed numbers of stars, together with the differences between them.

The last line of Table II shows that in no case does x reach the theoretical number 3.98, but in the case of the A stars it comes pretty near it. For types F, G, and K it approximates closely to 3.00. For M it is somewhat lower, and for B decidedly so. From this we conclude that in this direction the A stars are pretty uniformly distributed in space as far as the table goes, that is down to magnitude 9.0, but for the other types they are not so. Since the A stars are on the average more luminous than those of types F, G, and K, the constants belonging to them apply to a considerably greater distance from the Sun than those of the latter types. With the exception of type B the graphs were fairly straight lines, that is to say there was no evidence that the value of x altered with diminishing magnitude. For the B stars we obtained a curved line. This is indicated in Table III, the last column under B, where the first and last residuals are negative, and the three others positive. The value of x for this type, besides being very small, therefore apparently diminishes as we recede from the Sun.

When the other volumes of the *Henry Draper Catalogue* are completed, it will be of interest to see how far these constants hold for other portions of the galaxy. They certainly do not hold for the galactic polar regions however, as we shall see by what follows. Tables IV to IX are arranged for those regions precisely like Tables I to III for the galactic equator. In Tables I and VII we find that for every type there are more stars of magnitude 8.5 than of 9.5. In Table IV on the contrary the reverse is true. This is due to the fact, as explained in the catalog, that the southern instruments photographed rather fainter stars than the northern ones. The last line of Table VI has therefore been carried out to stars of mean magnitude 9.5, or to one magnitude fainter than Tables III and IX. We see however that in every case the residual

TABLE I

GALACTIC EQUATOR. DISTRIBUTION OF MAGNITUDES

Magnitude	B5	A5	F5	G5	K5	M5	Total	Per cent
2.5	1	1	1	...	1	..	4	0
3.5	3	...	1	...	...	..	4	0
4.5	4	2	1	...	4	..	11	1
5.5	15	8	6	3	4	..	36	2
6.5	30	36	16	15	22	1	120	6
7.5	65	89	51	37	99	5	346	18
8.5	113	405	146	110	164	10	948	49
9.5	44	236	49	35	44	5	413	22
10.5	4	23	1	1	2	..	31	2
Total.......	279	800	272	201	340	21	1913	100
Per cent....	15	42	14	10	18	1	100	...

TABLE II

GALACTIC EQUATOR. DETERMINATION OF CONSTANTS

Term	B	A	F	G	K	M
log a	1.00	0.48	0.48	0.28	0.48	9.52
a	10.0	3.0	3.0	1.9	3.0	0.3
log x	0.35	0.56	0.465	0.49	0.50	0.42
x	2.24	3.63	2.92	3.09	3.16	2.63

is strongly negative, indicating that the catalog is incomplete for stars of this brightness. The proper limit for the southern stars is probably 9.5 instead of 10.0. That is to say between magnitudes 9.5 and 10.0 many stars are lacking.

By Table V we see that for the southern G stars the value of x nearly reaches the theoretical number 3.98, and that for the F stars it does not fall very far below it. By Table VI we note, omitting the last line, that the residuals are all small for these two types, and that the value of x is therefore constant, as far as magnitude 9.0. For the other types excepting B, the same appears to be true, altho the A stars show a slight thinning out for magnitude 8.5. Turning to Table VIII under F we see that the theoretical value of x is at last reached, and the G stars are not far behind. By Table IX the residuals under G are found to be rather large, but irregular, but all the types save G and K show an unmistakable falling off for the fainter magnitudes. This is most marked for types A and F. Here we seem to be at last really coming to the end of the stars in this direction. Since the fainter magnitudes for G and K hold out, the result does not appear to be due to a lack of completeness in the catalog.

Let us now make the reasonable assumption that for all the stars of any given type in our vicinity, the same formula should apply in all directions, except in as far as it is modified by our approach to the limits of our system. Since the stars of type A are all of a fairly uniform luminosity, and very numerous, we should expect to get our best results from them. Since the dwarfs of type M are generally too faint to be found in the catalog, this type should give us a corroborative result. For type K the dwarfs would begin to affect the formula, increasing the number of faint stars, while this effect might be quite marked for types F and G. This in fact is what we find to be the case, for if we divide the number of observed stars in the northern and southern polar regions taken from Tables VI and IX, by the number of computed stars as determined by the formulae for the galactic equator, taken from Table III, we shall obtain the results given in Table X.

If there was no evidence that we were coming to the boundaries of our stellar system, the ratio should be unity in each case. If the number of stars increased towards the poles, as we receded from the Sun, more rapidly than towards the galactic equator, then the ratio should rise, and might exceed unity. If on the other hand

TABLE III

Galactic Equator. Comparison of Observation and Theory

Magnitude	B			A			F			G			K			M		
	O	C	D	O	C	D	O	C	D	O	C	D	O	C	D	O	C	D
4.5	8	10	− 2	3	3	0	3	3	0	0	2	−2	5	3	+ 2	0	0	0
5.5	23	22	+ 1	11	11	0	9	9	0	3	6	−3	9	10	− 1	0	1	−1
6.5	53	50	+ 3	47	40	+ 7	25	26	−1	18	18	0	31	30	+ 1	1	2	−1
7.5	118	112	+ 6	136	145	− 9	76	75	+1	55	54	+1	130	100	+30	6	6	0
8.5	231	251	−20	541	525	+16	222	219	+3	165	166	−1	294	302	− 8	16	16	0

TABLE IV

Southern Galactic Pole. Distribution of Magnitudes

Magnitude	B5	A5	F5	G5	K5	M5	Total	Per cent
2.5	..	..	..	..	1	..	1	0
4.5	1	..	..	..	..	1	2	0
5.5	1	4	2	1	10	..	18	1
6.5	4	6	10	13	15	3	51	4
7.5	2	17	26	53	44	6	148	11
8.5	..	24	97	135	118	6	380	28
9.5	..	40	132	259	169	7	607	45
10.5	..	15	38	61	32	1	147	11
Total........	8	106	305	522	389	24	1354	100.00
Per cent.....	1	8	22	38	29	2	100	......

TABLE V

SOUTHERN GALACTIC POLE. DETERMINATION OF CONSTANTS

Term	B	A	F	G	K	M
log a	0.00	0.20	0.02	0.00	0.57	0.00
a	1.0	1.6	1.0	1.0	3.7	1.0
log x	0.39	0.40	0.525	0.58	0.425	0.30
x	2.45	2.51	3.31	3.80	2.63	2.00

TABLE VI

SOUTHERN GALACTIC POLE. COMPARISON OF OBSERVATION WITH THEORY

Magnitude	B			A			F			G			K			M		
	O	C	D	O	C	D	O	C	D	O	C	D	O	C	D	O	C	D
4.5	1	1	0	0	2	−2	0	1	−1	0	1	−1	0	4	−4	1	1	0
5.5	2	2	0	4	4	0	2	3	−1	1	4	−3	10	10	0	1	2	−1
6.5	6	6	0	10	10	0	12	12	0	14	14	0	25	26	−1	4	4	0
7.5	8	15	− 7	27	25	+ 2	38	39	−1	68	60	+8	69	70	−1	10	8	+2
8.5	8	36	−28	51	63	−12	135	132	+3	203	204	−1	187	186	+1	16	16	0
9.5	8	89	−81	91	158	−67	267	442	−175	462	794	−332	356	495	−139	23	32	−9

TABLE VII

Northern Galactic Pole. Distribution of Magnitudes

Magnitude	B5	A5	F5	G5	K5	M5	Total	Per cent
4.5	..	1	..	1	3	1	6	1
5.5	1	11	4	2	10	1	29	4
6.5	..	22	13	8	21	2	66	8
7.5	1	17	47	21	46	4	136	17
8.5	1	28	86	126	115	3	359	46
9.5	..	4	28	93	43	2	170	22
10.5	..	2	4	6	5	..	17	2
Total........	3	85	182	257	243	13	783	100.00
Per cent.....	0	11	23	33	31	2	100.00	......

TABLE VIII

Northern Galactic Pole. Determination of Constants

Term	B	A	F	G	K	M
log a	9.40	0.64	0.00	0.00	0.72	0.00
a	0.25	4.4	1.0	1.0	5.2	1.0
log x	0.30	0.44	0.60	0.54	0.39	0.30
x	2.00	2.75	3.98	3.47	2.45	2.00

TABLE IX

Northern Galactic Pole. Comparison of Observation with Theory

Magnitude	B			A			F			G			K			M		
	O	C	D	O	C	D	O	C	D	O	C	D	O	C	D	O	C	D
4.5	0	0	0	1	4	−3	0	1	−1	1	1	0	3	5	−2	1	1	0
5.5	1	1	0	12	12	0	4	4	0	3	3	0	13	13	0	2	2	0
6.5	1	1	0	34	33	+1	17	16	+1	11	12	−1	34	32	+2	4	4	0
7.5	2	2	0	51	91	−40	64	63	+1	32	42	−10	80	78	+2	8	8	0
8.5	3	4	−1	79	251	−172	150	251	−101	158	145	+13	195	191	+4	11	16	−5

TABLE X

Ratios of the Number of Stars in the Polar Regions

Southern Polar Region

Magnitude	B	A	F	G	K	M
4.5	0.100	0.00	0.00	0.00	0.00	∞
5.5	.091	.36	.22	.17	1.00	1.00
6.5	.120	.25	.46	.78	.83	2.00
7.5	.071	.19	.51	1.26	.69	1.67
8.5	.032	.10	.61	1.22	.62	1.00

Northern Polar Region

Magnitude	B	A	F	G	K	M
4.5	0.100	0.33	0.00	0.50	1.00	∞
5.5	.045	1.09	.44	.50	1.30	2.00
6.5	.020	.85	.66	.61	1.13	2.00
7.5	.018	.35	.85	.59	.80	1.33
8.5	.012	.15	.68	.95	.65	0.69

we find the ratio progressively becoming less and less, it would indicate that we are approaching the boundaries of our system. For types F and G the ratio does not increase and is high, notably for the G stars near the southern pole, where it even exceeds unity. This can only be due to the fact that there really are more of these stars in a given volume of space towards this pole than towards the equator. There seems indeed to be a cluster of them in this direction. The G stars are more crowded to the south, and the F stars to the north. For the other four types the ratio falls off as we progress, and for types A and B the diminution is rather marked.

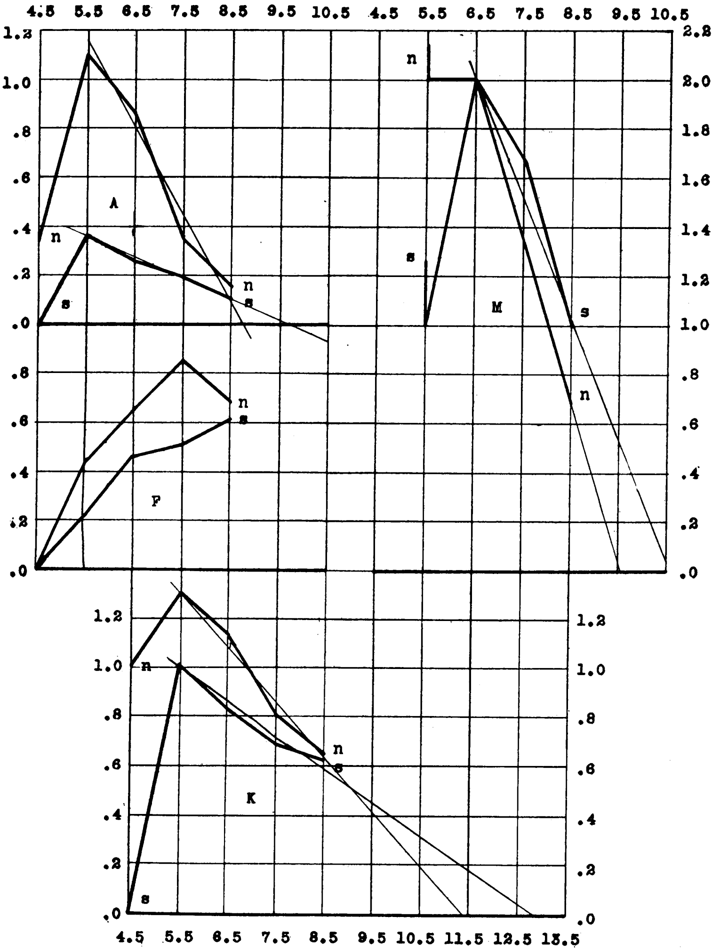

Figure 1

Plotting these ratios as ordinates, and the magnitudes as abscissas, we obtain for types A, F, K, and M the graphs shown in Fig. 1. For type G the graphs are similar to those for type F, and for B they are extremely flat, but otherwise similar to those of type M. The graphs of falling ratio, where there are enough stars, are as we might expect practically straight lines. Where they cross the zero ordinate, they indicate that there are no more polar stars, and that we have reached the boundaries of our system. For the southern galactic pole for type A they cross at magnitude 9.7, for type M at 10.6, for type K at 12.8, and for type B at 9.2. For the northern pole for type A they cross at magnitude 8.7, for type M at 9.5, for type K at 11.4, and for type B at 8.2. The latter result, altho confirmatory, is of little value, since so few stars are involved.

Subtracting the magnitudes for the northern pole from those for the southern, we obtain for type A 1.0 magnitude, for type M 1.1, for K 1.4, and for B 1.0. Mean difference 1.1 magnitudes. This indicates that the Sun is located 37.5 per cent, or three-eighths way, from the northern to the southern side of the galaxy. Omitting the results obtained by means of type K, which we believe to be vitiated owing to the presence of dwarf stars, we find a difference of 1.0 magnitude, corresponding to a distance of 38.8 per cent, indicating that the Sun is situated 11.2 per cent north of the median plane. The mean magnitude for these three types for the south pole is 9.8, and for the north pole 8.8, in each case 0.1 magnitude fainter than we found for the A stars alone. Since the stars of type A are far more numerous than those of types B and M taken together, and since their absolute magnitude is also better known, we shall confine our discussion hereafter to the stars of type A, merely stating that should we include the other types we should get a slightly larger, but less probable result. Our limiting apparent magnitudes therefore are for the southern galactic pole 9.7, and for the northern pole 8.7. Any stars fainter than these magnitudes in these directions are dwarfs.

The question of what absolute magnitudes correspond to given types of stars is at present in a very unsatisfactory condition. The discordances between the results obtained by different observers are large, and it is clear that the method can never give results of the highest accuracy. In *Popular Astronomy*, 1914, **22**, 290, 340, Tables V and VII, Russell divides the stars of type A into three groups, those whose parallax has been measured, those in clusters, and the double stars. In the first group the absolute magnitudes of stars of type AO and A4 are given as 1.4 and 2.5, whence we derive for A5 by exterpolation from his formula magnitude 2.8. In the second group he gives for the same types magnitudes 0.5 and 1.7, whence we derive for type A5 magnitude 2.0. Finally for the double stars Table VII he gives for type A5 magnitude 1.5. In obtaining the final results from Table V Russell rules out those stars whose parallax has been m asured, as being systematically nearer, and therefore smaller than the others of equal apparent magnitude. The mean absolute magnitude of type A5 derived from the two remaining groups is therefore 1.75.

Kapteyn in *Contributions From the Mount Wilson Observatory* **147**, 73, also divides the stars of type A into three groups, but in a different manner. From the stars in the vicinity of the *Orion* nebula he derives the absolute magnitude 3.47 for the type as a whole. From those in the *Pleiades* he derives the magnitude 4.79, and from those in the *Hyades* 2.26, mean value for the three 3.51. He concludes that the adopted value of the parallax for the *Hyades* is incorrect, and then modifies his results accordingly, obtaining for them 2.95, and for the *Pleiades* 3.74, and finally concludes, p. 84, that the absolute magnitude of a star of type A5 is 3.4.

This value we see differs from that according to Russell by 1.65 magnitudes, and is therefore only about one-quarter as bright. Fortunately types A and B are the ones on which they agree most closely. For a dwarf of type M, Kapteyn's value of the brightness is only one-one hundred and eightieth part of that of Russell. Adams and Joy in *Contributions from the Mount Wilson Observatory* **142**, 22, give a value for type M one-third that of Russell, and sixty times that of Kapteyn. As indicated in my paper on "The Parallax of the *Orion* Nebula," these PUBLICATIONS 1919, **31**, 86, Kapteyn's value of the parallax is almost certainly too large, and consequently his absolute magnitudes founded upon it must be too faint. An increase in the brightness of his *Orion* magnitudes would incidentally brighten those in the *Pleiades*, while leaving those in the *Hyades* unchanged. It would therefore bring his three values into much better accordance.

In what follows we shall adopt the value of 2.0 for the absolute magnitude of a star of type A5. This we notice, is the mean of Russell's result and Kapteyn's unmodified value for the *Hyades*. A change of one magnitude in this constant would change our resulting distances in the ratio of 1.6. Applying then the well known formula $m\text{-}M = 5 \log d$, where m and M are the apparent and absolute magnitudes, the distance d of the southern side of our galaxy appears to be 35 "dekaparsecs," and of the northern side 22, total **57**, or 1850 light years. The light year is too small a unit to employ conveniently for the vast spaces with which we shall deal in this paper, especially when we come to refer to volumes, altho it does well enough to indicate the distances of the nearer stars. We shall use it occasionally however on account of its general familiarity, and universal acceptance. The parsec, or 3.26 light years, is better, tho still too small. In this research we have adopted the dekaparsec (dps), or ten parsecs, which aside from its greater convenience in computation, is more suitable than either of the others with regard to its size. Since our Sun is as we have just seen 11.2 per cent north of the median plane, this distance becomes **6.4** dps, or 207 light years. Shapley by an independent method makes the distance 205. (*Communications Nat. Acad. Sci.* **54**, 5.)

We shall consider in this paper, as previously stated, that the stars of our stellar system form one huge flattened cluster, surrounded by a thinner plane of stellar material forming our galaxy, resembling somewhat, but in a very exaggerated form, the planet *Saturn* and its rings. It appears to the writer that the southern portion of our galaxy has never been adequately represented. Those astronomers who have never been south of Europe or the United States have never had a chance to see it to advantage, and those who have been farther south, have usually been occupied with other matters, and so have not had the time to make careful naked eye observations. Even photographs, altho unequalled for detail, fail properly to represent its general shape. The main difficulty in its delineation either in the case of drawings or photographs is its great angular size, which has caused it to be represented on too large a scale. When photographed on several different plates, especially if the contrasts are photographically exaggerated, we find that the same region will appear of quite a different intensity on one plate from what it will on another.

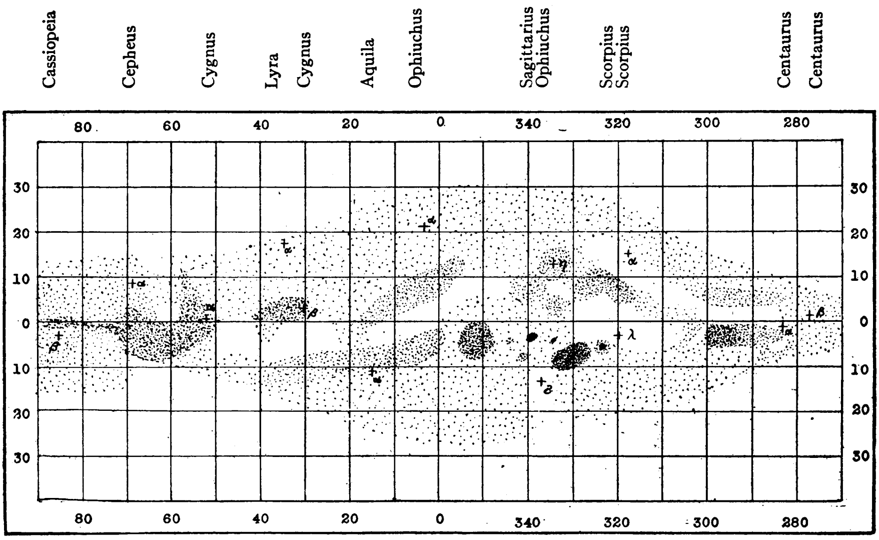

Figure 2

The writer has made a drawing, Fig. 2, extending from 90° thru 0° to 270° galactic longitude, or from near γ *Cassiopeiae*, thru *Sagittarius* to near α *Crucis*, which represents to his eye the general shape, and gives the more readily seen naked eye details. To give all the details would be a rather large undertaking, since after drawing one of them one would have to go out and stand in the dark for a considerable time, until the eye had reached its full sensitiveness, in order to see the next one, impress it on one's memory, and check one's representation of the first. Moreover, since this work has already been done much better by means of photography (*H. A.* **72** No. 3, and **80** No. 4), a complete visual representation appears to be unnecessary.

The brighter stars are represented in the figure by crosses, each designated by its proper Greek letter, the name of the corresponding constellation being placed above it. The darker the region is in the drawing, the brighter it is in reality. The extreme boundaries are hazy and seldom sharply defined. Indeed, we have not tried to represent the extreme limits of the galaxy, but rather an isophotal line near the limit in faintness, and rather less bright than the Gegenschein in September and October. The latter is always particularly conspicuous during these months, as was recently pointed out by Barnard (*Pop. Astron.* 1919, **27**, 109).

If due to sunlight reflected from countless meteors, this is precisely what we should expect, since more than half of *Jupiter's* comets come to perihelion during the autumn months, and doubtless innumerable other invisible comets or meteor streams are distributed according to the same law (*Pop. Astron.* 1919, **27**, 208).

The brighter areas of the galaxy are in general circular or elliptical in the central region near longitude 340°, but are accompanied by fainter extensions stretching away from it as we advance to either side. The star σ *Sagittarii* to the right of the middle of the drawing, is surrounded by a dark bay cutting into the general outline. This is not shown in the photographs, and is probably a subjective effect, due to the presence of a number of bright stars in that vicinity. Between σ and λ *Scorpii*, in *Sagittarius*, is the brightest large galactic area in the whole heavens. The large circular area in *Scutum* between σ and α *Ophiuchi* is the second brightest. Between these two bright regions are three small ones, all lying near galactic latitude $-4°$. The other bright areas seem to be symmetrically arranged about the middle one of these three, which is the very brightest area in the whole Milky Way, and the one showing the greatest concentration of bright stars as seen with the telescope. It is located in α 18^h07^m and $\delta - 20°$. Two small areas to the right of it appear brighter to the naked eye, but this is because they each contain an irregular cluster of a comparatively few bright stars.

According to the photographs, the whole region of the galaxy extending from longitude 60°, near α *Cygni* south to 260°, near α *Crucis*, 160° in length, appears to be composed of stars and luminous gas. The remaining 200° consists mainly of stars. The difference is well shown if we compare Plates 8 and 9 of the southern region, in the *Harvard Annals*, with Plates 6 and 7 of the northern.

The shape of the galaxy as it appears in Fig. 2 resembles that of those spiral nebulae which we are able to see edgewise. There is evidence that some of these such as N. G. C. 5457-8, Messier 101, are distinctly smaller than our system (*Communications Nat. Acad. Sci.* No. 29), but even if that were true of many of them, as may indeed be the case, that fact would not alter the resemblance, nor the plausible similarity of structure. It may be stated that according to our view our galaxy does not consist of a cluster of stars surrounded by a ring of gas, but rather of a cluster of stars and luminous gas surrounded by a ring of stars and dark clouds. This is indicated by the constitution of the different portions of the galaxy as above described. We may indeed consider the planet *Saturn* to be such a nebula in an advanced stage, and on a very small scale, both as to its rings and as to the central partly gaseous mass.

Even the dark ring has its analog, altho this may be only accidental. Reference is here made to the dark band lying between ourselves and the central galactic mass. It stretches conspicuously, as shown in the photographs, from longitude 50° near *α Cygni*, thru 0° to longitude 280° near *α Centauri*, distance 130°. Since nearly all of the globular clusters are located between these limits, it is quite obvious why none are found coinciding with the equator, as has been already otherwise explained by Shapley. In a narrowed shape it can be traced back as far as longitude 130°, near *α Aurigae*, and in the form of occasional dark areas near the middle of the bright region can be found on most of the plates of the galactic regions. It is undoubtedly due to absorption by clouds of non-luminous rarefied gases. That the band does not lie, in the case of the spiral nebulae that we see edgewise, exclusively outside of them, but is due in part to dark clouds diffused thruout their mass, is well shown in N. G. C. 4736, 224, 4631, and 4826. A photograph of the first of these is given in the *Contributions From the Mount Wilson Observatory*, **132**, Plate 12, and the others in the *Publications of the Lick Observatory*, **8**, Plates 1, 41, and 45. This explains why the absorption is so clearly seen between us and the central mass of the galaxy.

Among the larger and brighter spirals there are three whose equators pass nearly thru the Sun. They are all represented in the Lick collection of photographs, and from these certain measurements have been made which are recorded in Table XI. The first two columns give the N. G. C. number and the number of the Plate. The next four give the thickness, *T*, of the outer ring in millimeters, at half the distance from the center to the circumference, the polar diameter, *P*, of the central condensation, the equatorial diameter, *E*, and the diameter of the surrounding ring, *R*. The last three columns give the ratios of these quantities.

Some writers are in the habit of referring to the spirals as if they had in general only two arms. While this is true in several cases, yet in many others three or more arms can be detected, and in some cases matter is seen to be flying off the circumference all around the rim, like water off a wet grindstone. This is well illustrated in several of the plates of the *Mount Wilson Contributions* **132**, notably 10, 12, and 14, also in Plates 44 and 46 of the *Lick Publications* **8**.

Turning now to the mean ratios given in the last line of Table XI, we see that even in the extreme cases the individual ratios do not vary very greatly from them. If therefore we apply these means to the case of our galaxy it would appear that our derived results should not be very far out of the way. One of the ratios, E/P we can indeed test directly. In Fig. 2 the angular polar diameter of the fainter regions is 58°, or if we use the brighter regions it is 30°. The fainter regions are very faint, and the brighter regions appear to be more nearly comparable to what we see when we view the spirals thru a telescope. We shall therefore adopt 30° as the apparent polar diameter of the central mass. Similarly the equatorial diameter for the brighter regions appears to stretch from 20° to 300°, or thru 80°. Let us then assume a spheroid whose apparent angular polar radius is 15°, and its equatorial 40°. It may readily be shown that the real ratio of its diameters is 5.4, which compares with the ratio 4.5 given by the table. The difference only affects the diameter E materially. We shall have to assume the other ratios P/T and R/P, since there is no method of checking them, whence $R = 25.3T$.

TABLE XI

MEASURES OF SPIRAL NEBULAE

N. G. C.	Reference	T	P	E	R	P/T	E/P	R/P
891	6	4.0	6.0	16	57	1.5	2.7	9.5
4244	31	1.5	3.5	31	67	2.3	8.9	19.1
4565	40	3.5	6.5	12	74	1.9	1.8	11.4
						1.9	4.5	13.3

We have already found the thickness of our galaxy in the vicinity of our solar system to be 57 dps. Let us call this quantity t, and assume that the thickness of the galactic ring varies uniformly from the central mass out to a sharp edge at its circumference, as appears to be the case with the spiral nebulae, and as should be nearly the case from theoretical considerations. Let us call x the distance of the Sun from the center, and $2T$ the thickness that the ring would possess if it reached to the center of the spheroid. Then by simple proportion we have $x=R/2-Rt/4T=12.65T-360$.

If the ratio of the diameters of the spheroid is 5.4, the true angular polar radius would be 8°.67, and we should have $x=P/2 \tan 8^\circ.67=6.23T$, whence, combining with the above, we obtain $T=56.1$ dps. From this it follows that $x=349$, $P=107$, $E=575$, and $R=1420$ dps. It will be noticed that double the thickness T equals 112, and is therefore practically identical with the polar diameter 107. Our system may consequently be considered as a flattened double cone, the central spheroid lying within, and tangent to the conical surfaces. The distance of our Sun from the center of the stellar universe, 349 dps, is equivalent to 11,400 light years. Shapley places it at 2,000 dps, or nearly six times as distant. (*Contrib. Mt. Wilson Obs.* **161**, 10.) The direction of the center appears to be in galactic longitude 340°, galactic latitude −1°, or in the constellation *Sagittarius* in α 18^h05^m, δ $-18^\circ.1$. Shapley places it in galactic longitude 325°. (Compare Fig. 2.) The isophotal line corresponds more nearly to a location of the center in longitude 346°, but this deviation from our adopted value of 340° may be caused by atmospheric absorption, due to the northern position of our station, located in latitude −18°.

Shapley assumes that the center of the galaxy and the center of the globular clusters coincide. This seems natural and plausible, but he makes no attempt to prove it. Probably it cannot be proved. If we look at the projection of the clusters in the galactic plane, as shown by him in Fig. 1, *Mt. Wilson Contributions* **157**, and also perpendicular to it, as shown in **161** Fig. 3, we shall see that they are most concentrated at a distance of about 1300 dps from the Sun, and that beyond that they become more and more sparse, till they gradually fade away in the distance. This distribution might lead us to believe that while moving about among themselves, they were all traveling together towards us thru space like a comet, or a swarm of meteors, and that their center had not yet reached the center of our stellar system. This view is corroborated by Slipher's measures of the radial velocity of ten globular clusters, lying between galactic longitudes 35° and 307° (compare Fig. 2), only one of which, a faint and therefore difficult one, is found to be rapidly receding from the Sun. Its motion is so different from that of all the others that it has been rejected. The other nine, three of which are nearly stationary, are approaching with a mean velocity of 133 km. per sec. (*Mt. Wilson Contributions* **157**, 12.)

In *Mt. Wilson Contributions* **152** Plate IV, Shapley represents by a circle the diameter of an average globular cluster as about 2 dps. In **157**, 6 he states that the diameter of such a cluster is 15 dps. This would be represented on his plate by a circle 7.5 inches in diameter, and therefore refers to the extreme outer limits, and not to what might be understood by looking at the plate. In the description of Fig. 1 in **157**, above mentioned, he states that the black dots are about five times the relative size of the clusters. This must again refer to the extreme outer limits, since the circle which he has drawn in Plate IV would be only one-fiftieth the size of the dots, and this would appear to give a better idea of the relative size and distribution of the clusters.

Assuming the correctness of Slipher's and Shapley's results for the globular clusters referred to in *Mt. Wilson Contributions* **157**, 12, and rejecting N. G. C. 6333 as faint, discordant, and therefore perhaps doubtful, we find that the other nine clusters are at a mean distance from our Sun of 1690 dps. Their mean distance from the center is therefore approximately 1340 dps. If their speed were entirely due to gravitation, and the clusters were coming from an infinite distance, we could at once determine the total mass of our system plus that of the clusters. While these two suppositions may not be justified, the computation will at least give us a probable maximum figure for the mass. The result is 27,400 million times the mass of our Sun, of which all but an insignificant fraction is due to the mass of our system, and may be vaguely taken as representing the total number of stars that it contains. Of these we have been able to detect hitherto, with our largest telescopes, but one or two per cent.

As a check on this result, the volume of our system in spherical dekaparsecs, that is to say, in terms of a unit sphere whose radius equals one dps is 28,000,000. We therefore find on the average 970 stars per sph. dps. Within the sphere whose center is at our Sun, and whose radius is 0.5 dps, *i. e.*, $\pi = 0''.20$, there are 22 stars counting binaries as single stars, or 30 stars in all, as far as we know. With the same density there would be 240 stars in the sph. dps centered at our Sun. This figure checks as nearly as we could expect with the 970 stars found above.

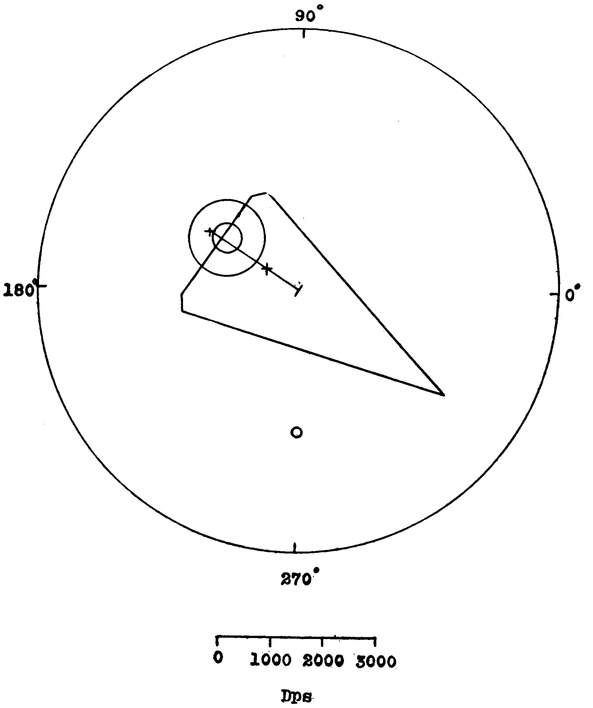

Figure 3

The majority of them occupy a somewhat triangular area, and this is shown in Fig. 3, which enables us to form a comparison between Shapley's sidereal system and the one derived from the present investigation. In **157**, 6 he gives the diameter of his system as equivalent to 10,000 dps. This result is represented by the large circle whose center is, according to his statement, 2000 dps from the upper cross, which represents the location of our Sun, and is located in galactic longitude 325°.

The lower cross located at 1300 dps from us indicates the position where the clusters are most congested (see also **152**, 23). The medium sized circle, which passes near it, shows the extreme extent of our galaxy, some 1420 dps in diameter, according to the present investigation. The smaller concentric circle represents the equatorial diameter of the spheroidal mass. The smallest circle, situated below the center of the figure, is 100 times the visual diameter of the average globular cluster. The scale divisions are 1000 dekaparsecs. If the majority of the clusters, some eighty in number, are approaching the Sun at the average speed of the nine above mentioned, which have already been measured, their center of congestion should reach the center of the two concentric circles in a little less than 70,000,000 years, a very brief interval in the history of our stellar system, or even of our Earth according to the latest information. There seems therefore to be no special reason to assume that the center of the galaxy and the center of the clusters should happen to coincide at the present time.

Judged by the brightness of the novas which have appeared in the *Andromeda* nebula, which must be one of our nearer neighbors in outer space, its distance can hardly be less than one hundred times that of our galaxy, as pointed out by Curtis, *Adolfo Stahl Lectures*, 107. Calling the distance of the galaxy half its radius, the distance of the *Andromeda* nebula is at least twenty-five times the diameter of our system, 36,000 dps or 1,160,000 light years. On the scale of Fig. 3 it would be situated at a distance of about 10 inches from our Sun. From the *Andromeda* nebula our system would present an angle of 2°.3. The angular diameter of the *Andromeda* nebula on the Lick photograph is at least 0°.8. It cannot therefore be less than one-third the diameter of our system, and is probably larger. There are doubtless plenty of other nebulae more remote and larger still, so that it seems likely that we are only one of many stellar universes.

Indeed if the *Andromeda* nebula were removed to one hundred times its present distance, it would still be clearly visible in our larger telescope, showing as an object of the fifteenth magnitude. There are countless nebulae as faint as this scattered thruout the sky. It is probable therefore that our larger telescopes are capable of detecting and recognizing nebulae one hundred times as remote as that in *Andromeda*, or at a distance of 3,600,000 dps, and that the diameter of that portion of space accessible to our inspection is therefore at least 200 million light years.

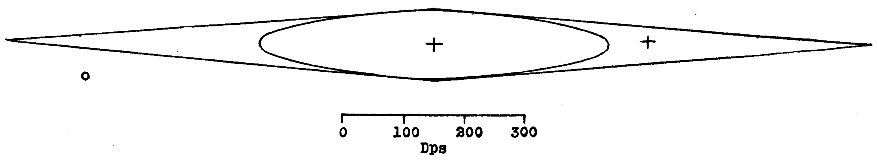

Figure 4

Summarizing our results, we find that we appear to be located in a flattened ring of stellar matter surrounding the central ellipsoid of our system. The thickness of this ring in our vicinity is 57 dps, or 1,850 light years, and its thickness half way from the center to the circumference 56 dps, or 1,830 l. y. Our distance north of the median plane is 6.4 dps, or 207 l. y. The polar diameter of the central cluster is 107 dps, or 3,470 l. y., the equatorial 575 dps, or 18,800 l. y., and the extreme diameter of the outer ring 1,420 dps, or 46,000 l. y. Our distance from the center, which is located in galactic longitude 340°, galactic latitude $-1°$, α 18^h05^m, $\delta - 18°.1$, is 349 dps, or 11,400 l. y. It is therefore almost exactly half way from the center to the circumference. In Fig. 4, a cross section of our galaxy as above computed is drawn to scale. The small circle is drawn of ten times the visual diameter of the average globular cluster. The location of the Sun is indicated by the small cross on the right. It may be remembered that the distance of *Sirius* is one quarter of one dekaparsec. A comparison of this theoretical drawing may be made with the photographs of N. G. C. 891 and 4565, *Lick Publ.* **8**, Plates 6 and 40.

Mandeville, Jamaica, B. W. I.
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